SITE PREPARATION FOR RED OAK PLANTATION ESTABLISHMENT ON OLD FIELD SITES IN SOUTHERN INDIANA

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Abstract: Little research has been conducted on the use of mechanical site preparation or fertilization in the Central Hardwood Region. Many hardwood plantings, particularly oak plantings, on old field sites in the region have resulted in high rates of mortality, stem die-back, and slow early-growth rates. The purpose of this study was to investigate the effect of mechanical site preparation techniques and fertilization on the early survival and growth of northern red oak (*Quercus rubra* L.) seedlings planted on an old field site in southern Indiana. The study was initiated in the Spring of 1993 on a severely eroded old field site, which had a history of successive plantation failures. The treatments included all possible combinations of subsoiling, tillage, and fertilization. Each treatment combination was replicated four times. Subsoiling was accomplished to a 45 - 50 cm depth. Conventional tillage consisted of a three bottom moldboard plow followed by disking to a tillage depth of approximately 25 cm. Fertilization consisted of 336 kg nitrogen/ha, 98 kg phosphorus/ha, 93 kg potassium/ha, 224 kg calcium/ha, 56 kg magnesium/ha, 112 kg sulfur/ha, and 560 kg lime/ha. Seedling survival, diameter and height growth, root growth parameters, and foliage nutrient concentrations were measured. Deer browsing was also monitored. After one growing season, survival exceeded 99% over all treatments. Fertilization produced a 47% and 60% increase in height and diameter growth, respectively, over the unfertilized treatments. Subsoiling and tillage did not appear to significantly increase tree stem growth. Fertilized seedlings had higher foliar N concentrations, dark green foliage and 2.1 growth flushes during the first growing season compared to the yellow-green foliage and the 1.2 growth flushes produced by unfertilized seedlings. Fertilized trees were favored by the deer for browse, but resprouted vigorously following browsing. Nitrogen was the main factor limiting tree growth. Fertilization enhanced height growth by inducing multiple growth flushes throughout the growing season. Because the results of this study are preliminary, treatment effects will be monitored through the establishment phase of the plantation.

INTRODUCTION

The land-use history of southern Indiana is typical of the Midwest. From the early 19th century to the present, there has been a repeated cycle of land clearing, agronomic crop production and livestock grazing, soil erosion, declines in soil fertility, abandonment, natural succession, and once again, clearing (Callahan 1973). Within the past 30 years, economics and government farm policies have generated land clearing/reforestation cycles.

In the past, reforestation of old fields occurred through natural succession, resulting in dense stands of sassafras and other low-value species. High-value timber species such as the oaks were established only after long periods of time. Government cost-share programs such as Conservation Reserve Program (CRP) and Stewardship Incentive Program (SIP) along with upward price trends in hardwood timber markets have encouraged more landowners to realize the potential value of high quality hardwood forests. More and more landowners desire to establish hardwood plantations of known stocking. There has been mixed success with hardwood plantings on old field sites in southern Indiana. Repeated stem dieback or extremely slow initial growth often results in high mortality and subsequent low stocking (McGee and Loftis 1986, Pope 1993, Russell 1971).

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Much of the research on artificial regeneration of oaks in the *Central Hardwood Region* has concentrated on tree improvement, planting stock improvement, mycorrhizal inoculation, weed control, vertebrate pest control, and the use of tree shelters (Pope, 1993). Intensive plantation establishment measures, such as mechanical site preparation and fertilization, have not been as extensively investigated in the region. Mechanical site preparation has been studied quite extensively and is widely accepted in the south particularly with the regeneration of southern pine (Berry 1979, Burger and Pritchett 1988, Lantagne and Burger 1983, Miller and Edwards 1985, Morris and Lowery 1988). Malac and Heeren (1979) discuss the use of disking and subsoiling for improving soil conditions and reducing perennial herbaceous weed competition when establishing oaks in old fields. Seifert and others (1985) studied the effects of bedding and disking on the establishment of swamp chestnut oak (*Quercus michauxii* Nutt.) on a poorly drained site in southeastern Indiana. After five growing seasons, 52% of the seedlings in the disked treatment and 45% in the disked and bedded treatments were taller than the overall mean seedling height (152 cm) compared to 16% for the control seedlings. Subsoiling fractures restrictive layers thus allowing deeper root penetration early in the tree establishment phase and providing a greater volume of soil for root exploitation (Berry 1979, Lantagne and Burger 1983). Miller (1993) outlines a "general plantation establishment prescription" for oaks including the use of mechanical site preparation.

Fertilization has been extensively researched and widely practiced in coniferous forests of the South and the Pacific Northwest (Allen 1987), but relatively few studies have examined hardwood species response to fertilization. Foster and Farmer (1970) reported significant growth responses following nitrogen fertilization of planted northern red oak in Tennessee. Auchmoody and Smith (1977) reported on the response of natural yellow-poplar and red oak stands to fertilization in West Virginia. Johnson (1980) studied the effects of fertilization with 112 kg N/ha and 244 kg P/ha on five different species of oak seedlings planted in the Missouri Ozarks. Following eight growing seasons, fertilization significantly improved scarlet oak (*Quercus coccinea* Muenchh.) survival and significantly increased the number of black oaks (*Quercus velutina* Lam.) and scarlet oaks attaining a 6, 8, and 10 feet minimum height. Northern red, white (*Quercus alba* L.) and post (*Quercus stellata* Wangenh.) oaks did not respond significantly to fertilization.

The purpose of this study was to investigate the effect of the following three intensive site preparation methods and their combinations on first growing season survival and growth of northern red oak (*Quercus rubra* L.) seedlings planted on an old field site in southern Indiana:

1. subsoiling
2. tilling (plowing & disking)
3. fertilization.

METHODS

Site Description

The study was initiated in the Spring of 1993 on a one ha old field site located in the unglaciated sandstone-shale uplands of southern Indiana, in the Crawford Upland Section of the Shawnee Hills Natural Region (Homoya and others, 1985). The site was abandoned from agricultural use approximately 40 years ago. The soils are characterized by moderately thick loess deposits over paleosols on residuum formed from acid siltstone and sandstone. Because of past management history, most of the loess cap has been eroded away. The soils are fine-silty, mixed, mesic Typic Fragiudalfs of the Zanesville series, with a fragipan at a 60 cm depth. Because of the fragipan, the site has a perched water table during the winter and spring. The site is a south facing aspect with a 6% slope. It is severely eroded, presently dominated by broomsedge, and has a history of plantation failures. The average growing season temperature is 26°C, and average annual precipitation is 92.7 cm.

Study Design and Installation

The experimental design was a completely randomized 2x2x2 factorial with a split plot (nested design), with 4 replications and a total of 32 whole plot treatment units. The area of each whole plot treatment unit was 95 m^2. The whole plot treatments consisted of factorial combinations of subsoiling, tilling, and fertilization. The following are the eight treatment combinations:

1. control
2. fertilize
3. subsoil
4. subsoil + fertilize
5. till
6. till + fertilize
7. subsoil + till
8. subsoil + till + fertilize.

Subsoiling was accomplished in late April 1993 using a single-tine subsoiler drawn by a 80-horse-power farm tractor; equipment readily available to most landowners within the region. This produced a 45-50 cm deep slit. This was not sufficient to fracture the fragipan, but did produce a zone of fracture in the dense, clayey B_t soil horizon. In mid-May, tilling was accomplished by plowing with a 3-bottom moldboard plow followed by disking to a 20-25 cm depth.

Fertilizer was applied in late April 1993, prior to plowing and disking. Fertilization consisted of a broadcast application of urea, monoammonium phosphate, potassium-magnesium sulfate, and a fast-reacting pelletized calcitic lime, resulting in the application of 336 kg N/ha, 98 kg P/ha, 93 kg K/ha, 224 kg Ca/ha, 56 kg Mg/ha, and 112 kg S/ha. These fertilizers were chosen to provide an ample supply of all plant macronutrients and to ensure that none of these elements would become limiting (Blinn and Buckner 1989).

Within each of the 32 whole plot treatment units, three different types of 1-0 northern red oak seedlings were planted. Seedling type or planting stock was the split or nested plot treatment. The following describe the three seedling types and the number planted in each split plot treatment (Table 1):

1) 15 standard state nursery seedlings; average caliper 5.7 mm; average height 44.5 cm.

2) 4 bareroot seedlings grown under enhanced nutrient and moisture regime; average caliper 6.3 mm; average height 50.1 cm.

3) 5 containerized seedlings grown under enhanced nutrient and moisture regime; average caliper 5.8 mm; average height 49.1 cm.

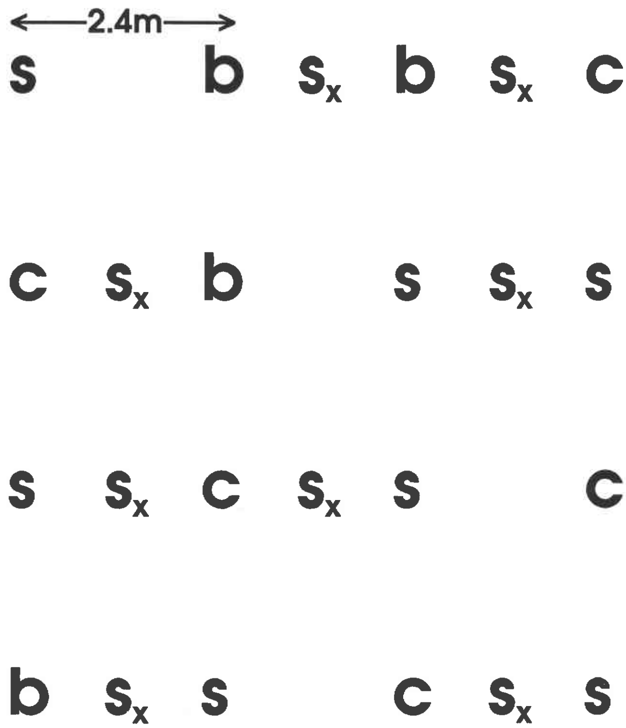
A total of 24 seedlings were planted in random fashion in each whole plot treatment unit in mid-May. All but eight of the standard state nursery seedlings were hand planted using a post hole digger on a 2.4 m x 2.4 m spacing. Trees were planted directly into subsoiled slits where that treatment occurred. All planting rows were carefully surveyed prior to treatment installation so that subsoiled slits could be readily relocated where subsoiling was followed by disking. The remaining eight standard state nursery seedlings were planted with a post hole digger on a 1.2 m x 2.4 m spacing for later excavation and root growth analyses (Figure 1).

Chemical weed control was applied uniformly over all treatments and consisted of the application of a tank mixture of simazine and atrazine, each at a rate of 2.24 kg a.i./ha at the time of planting, and glyphosate at a rate of 2.66 kg a.i./ha in July. Herbicide was applied with a backpack sprayer in 110 cm bands in the planting row. Care was taken to prevent drift onto the seedlings during the glyphosate application.

Table 1. Mean diameter growth and height growth for three different northern red oak planting stock.

Planting Stock	n	Diameter Pre-plant	Diameter Year 1	Diameter Growth	Height Pre-plant	Height Year 1	Height Growth
		(mm)	(mm)	(mm)	(cm)	(cm)	(cm)
Std. Nurs.	480	5.71 a[1]	7.69 a	1.86 a	44.5 a	57.6 a	12.2 a
Spec. Bare.	128	6.30 b	9.20 b	2.90 b	50.1 b	71.3 b	21.2 b
Spec. Cont.	160	5.76 a	10.05 c	4.22 c	49.1 b	71.5 b	21.9 b

[1]Different letters indicate statistically significant differences at α=0.01 level of significance.



s = standard nursery stock
s_x = standard nursery stock - excavate
b = enhanced bareroot stock
c = enhanced containerized stock

Figure 1. Example of the layout of a single whole plot treatment unit.

Measurements

Caliper and height were measured on all seedlings prior to planting. The trees were measured for total height and groundline diameter following the first growing season (1993). The number of growth flushes for each seedling were recorded as well as evidence of deer browse. On November 1, 1993, observations on tree dormancy were made. The number of trees that were not yet completely hardened off were recorded.

Following the first growing season, four of the eight standard state nursery seedlings planted for later excavation were randomly selected from each whole plot treatment unit and carefully excavated to obtain the entire root system. Lateral root development, in both a north-south and an east-west direction, and total root depth were measured in the field at the time of seedling excavation. A root volume index (RVI) was calculated by using the average between north-south and east-west lateral root extent measurements and the total root depth in the formula for the volume of a cylinder. This provided an index of the soil volume exploited by the roots.

First order laterals greater than 1 mm in caliper were counted on each of the excavated seedlings. Total length of first and second order laterals greater than 1 mm in caliper were also measured. Excavated seedlings were then clipped to sever roots from stem, oven dried at 65°C to a constant weight, and weighed to obtain stem biomass, root biomass, and total biomass. Root:shoot ratios were also calculated.

Foliar Analysis

In late July 1993, one fully expanded leaf from the top one-third of the crown was sampled from each tree in each whole plot treatment unit. All leaves sampled from a single whole plot unit were composited. Leaf samples were oven dried at 65°C and ground to pass a 1 mm sieve. Total nitrogen was determined using the micro-Kjeldahl method described by Nelson and Sommers (1973). Total P, K, Ca, and Mg were determined using wet digestion in nitric acid and hydrogen peroxide followed by analysis by inductively-coupled plasma emission spectrometry (ICP).

Data Analysis

Availability of the different seedling types used in this study precluded planting equal numbers of each type within each whole plot unit. Because of the resulting unbalanced designed, a general linear model analysis of variance (GLM-ANOVA) was used to test for overall treatment differences. In analyzing the site preparation treatment effects, the means of all three seedling types were pooled. To provide for temporal consistency in the study, the trees that were excavated in 1993/94 were excluded from the analysis of stem parameters. Root parameter data was of course only collected on the excavated trees. Fisher's least-significant difference (LSD) mean separation procedure was used to find individual treatment differences following the GLM-ANOVA. Correlations between foliage nutrient concentrations and tree growth parameters were made using simple linear regression.

RESULTS AND DISCUSSION

With the exception of mole damage to three seedlings in one of the control plots, herbicide damage to one seedling in one of the disked and fertilized plots, and damage caused by unknown agents to two other seedlings, each in separate plots, survival was over 99% across all treatments following one growing season. This may be in part attributable to the above normal rainfall that occurred throughout parts of the growing season; e.g., growing season precipitation averaged 2.4 cm/month above normal.

Planting Stock

Both the bareroot and containerized stock grown under enhanced moisture and nutrient conditions were significantly taller at the time of planting than the standard nursery stock (Table 1). After one growing season both the bareroot and containerized special planting stock were about 71 cm in height compared to 58 cm for the standard stock and they had over 75% greater height growth than the standard stock. Although the special containerized stock did not have significantly greater diameter than the standard stock at the time of planting, following one growing season it did have 46% and 127% greater diameter growth than the special bareroot stock and the standard nursery stock, respectively. No significant interactions were detected between planting stock and site preparation treatments, therefore different seedling types did not respond in a different manner to the various treatments (Figure 2).

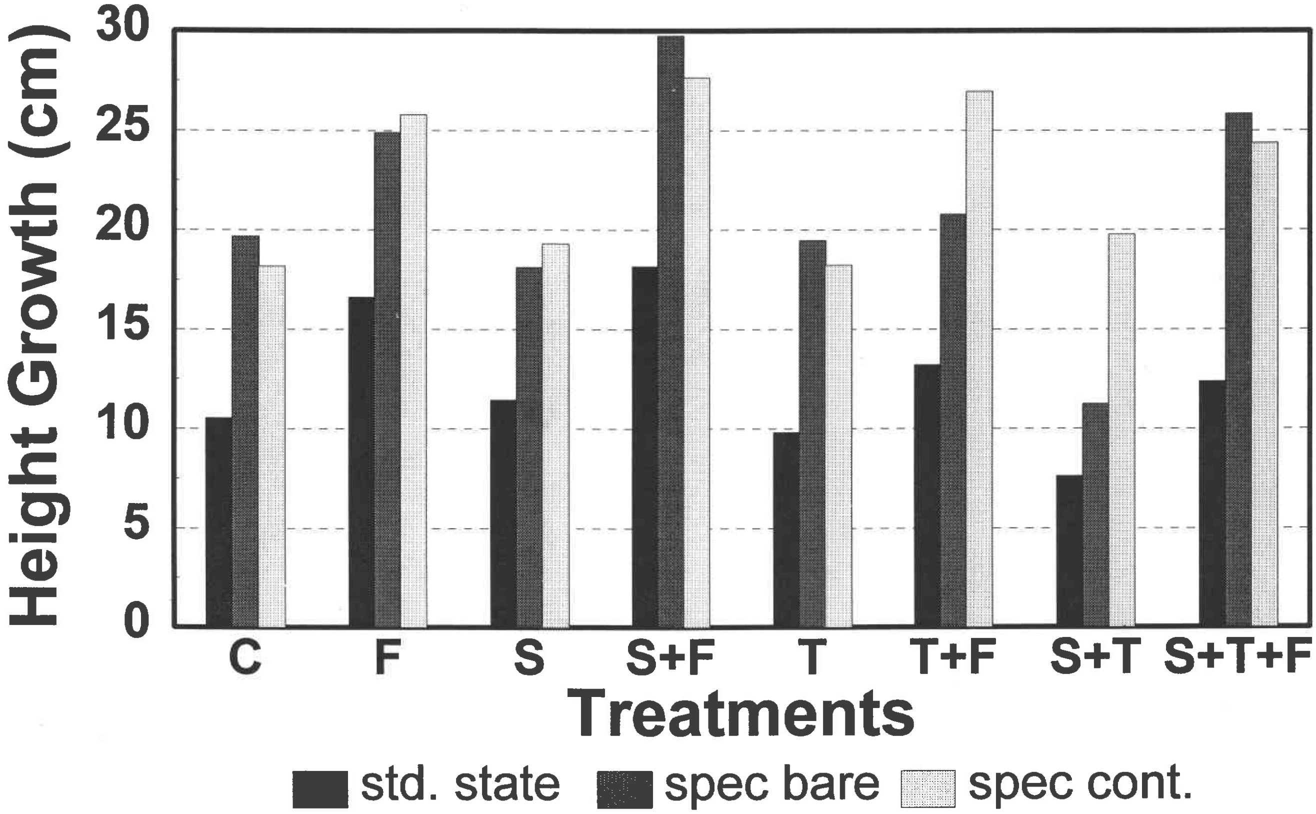


Figure 2. Year 1 height growth of northern red oak by site preparation treatment combination and seedling type.

It is generally believed that larger hardwood planting stock performs better upon outplanting than smaller planting stock (Gordon 1988, Stroempl 1985, Zaczek and others 1991). The results of this study concur with the conclusions of previous research.

Site Preparation Treatments

Root morphological characteristics. With the exception of root depth, subsoiling had little effect on root characteristics following one growing season. The roots of excavated red oak trees growing in subsoiled treatments penetrated to an average depth of 54.2 cm in the first growing season, compared to 48.3 cm for the non-subsoiled treatments (Table 2). In a year of normal or below-normal precipitation, root depth penetration during the first growing season following planting may be more critical to tree survival and growth. However, unless there is a hardpan within 45-50 cm of the soil surface, subsoiling may not produce enough additional tree growth to justify costs. On the other hand, many tree planting machines are equipped with a deep set shoe that produces a similar effect to subsoiling. Rooting depth may prove to be an important factor in subsequent years of the tree establishment phase.

Table 2. Root morphological parameters for excavated standard state nursery seedlings growing under factorial combinations of subsoiling, tilling, and fertilization.

Treatment	n	Depth[1]	Root[2] Volume Index	1st & 2nd[3] Order Lateral Length	No.[3] 1st Order Laterals	Fibrous	Biomass[4]	Root: Shoot
		(cm)	(cm³)	(cm)		(%)	(g)	
Subsoil								
No	64	48.3 a[5]	183097	554	17.7	39	45.0	1.37
Yes	64	54.2 b	229473	582	18.7	23	46.5	1.37
Till								
No	64	49.9	162296	507	17.4	20 a	43.4	1.36
Yes	64	52.6	250273	629	19.0	42 b	48.1	1.38
Fertilize								
No	64	48.8	170525	523	17.8	47 a	42.6 a	1.38
Yes	64	53.7	242045	614	18.5	16 b	49.0 b	1.36

[1]Total depth of root penetration into the soil.
[2]Calculated from the mean of the north-south and east-west measured lateral root extent and root depth used in the formula for a cylinder. Meant to approximate the total volume of soil being exploited by the root system.
[3]Caliper greater then 1 mm.
[4]Oven-dry weight of roots
[5]Different letters indicate statistically significant differences at α=0.05 level of significance.

Tilling, as well, appeared to have little effect on root characteristics (Table 2). Although the mean rooting volume index for the tilled treatment was substantially larger (54%) than that for the non-tilled treatment, the inherently high level of variation precluded any differences from being statistically significant.

Fertilization resulted in trees with greater total root biomass (49 g) than non-fertilized trees (42.6 g) (Table 2). Fertilization did not affect the root:shoot ratios of the trees. None of the treatments had a significant effect on the number of first-order lateral roots greater than 1 mm in diameter nor on the total length of first- and second-order lateral roots greater than 1 mm in diameter.

The importance of early root growth and development in northern red oak seedlings is reported in Grime and Jeffrey (1965). Crow (1988) underscores the importance of a "large, well-developed, well-established root system" as a "key factor related to rapid seedling growth." Repeated shoot dieback is reported to be an adaptive strategy of northern red oak in building up a sufficiently large root system and increasing the root:shoot ratio. Fertilization may aid in the early development of a larger root system without the loss of stem growth due to dieback.

Stem growth. Fertilization increased height growth by 47% and resulted in a mean tree height over 5 cm greater than that for non-fertilized trees after one growing season (Table 3). Fertilization also increased diameter growth by 60%. There were no significant interactions in height growth among site preparation treatment effects (Figure 2). Neither subsoiling nor tilling increased height or diameter growth after one growing season. In fact tilling appeared to have a marginally negative, though not statistically significant effect on height growth. Both tilling and fertilization produced greater stem biomass in the excavated trees, while fertilization alone produced greater total tree biomass than non-fertilized treatments (Table 3).

Table 3. Mean diameter and height growth for nonexcavated northern red oak averaged across all seedling types and stem biomass, and total tree biomass for excavated standard state nursery northern red oak growing under factorial combinations of subsoiling, tilling, and fertilization.

Treatment	n	Diameter Pre-plant	Diameter Yr. 1	Dia. Growth	Height Pre-plant	Height Yr.1	Ht. Growth	Shoot[1] Biomass	Tot.[1] Biomass
		(mm)			(cm)			(g)	
Subsoil									
No	318	5.87[2]	8.76	2.80	47.6	66.5	18.3	32.5	77.5
Yes	318	5.98	9.21	3.19	48.2	67.1	18.5	34.0	80.5
Till									
No	318	6.00	8.81	2.79	47.8	68.1	20.1	31.8 a	75.2
Yes	318	5.85	9.15	3.19	48.0	65.5	16.8	34.7 b	82.8
Fertilize									
No	318	5.88	8.27 a	2.33 a	47.2	64.0 a	14.9 a	30.8 a	73.4 a
Yes	318	5.97	9.69 b	3.66 b	48.6	69.5 b	21.9 b	35.7 b	84.7 b

[1]Only includes excavated trees which were all standard nursery stock.
[2]Different letters indicate statistically significant differences at α=0.05 level of significance.

Fertilization increased the number of flushes during the growing season (Table 4). Non-fertilized trees averaged 1.2 flushes while fertilized trees averaged 2.1 flushes. Subsoiling did not influence numbers of flushes, but tilling negatively influenced the number of flushes. In fact there appeared to be an interaction between tilling and fertilization; tilling reduced the number of flushes occurring in fertilized treatments (Figure 3).

Tilling appeared to reduce the ability of fertilization to induce multiple growth flushes, in the first growing season. One explanation for this phenomenon might be the more open, harsh environment that tilling creates for the above-ground portion of the seedling. In non-tilled treatments, fertilization resulted in the growth of tall, luxuriant herbaceous vegetation between the planting rows. Excellent weed control within the planting row removed competition for moisture and nutrients but allowed between-row vegetation to moderate sunlight and wind exposure and thus moderate soil moisture and temperature and ambient air temperature immediately around the seedlings. Herbaceous growth between planting rows in the tilled treatments was low growing and relatively sparse. Crow (1988) cites a number of studies that indicate that northern red oak benefits from partial shade because of its moderating influence on temperature and evapotranspiration, while young, newly established seedlings may suffer from water stress under full sunlight. Thus, greater exposure that resulted from tilling may have reduced the trees' ability to produce multiple growth flushes, even under the favorable moisture conditions of the 1993 growing season and the abundant nutrient supplies of the fertilization treatment.

Tilling may have also resulted in increased N leaching losses. Unless surface soil compaction is a major concern, tilling may produce no early growth advantages where effective chemical weed control is used. Tilling also raises erosion and water quality concerns, particularly on the extremely erosive soils of the unglaciated region of southern Indiana. However, tilling may provide more long-term benefits that will be realized in future growing seasons.

There is a concern that excessive fertilization may delay winter dormancy in hardwoods and result in frost or winter damage. On November 1, 1993, 9% of the fertilized trees were not yet dormant, while only 1% of non-fertilized trees were not yet dormant (Table 4). This is not a perfect measure of the length of growing season created by the different

Table 4. Mean number of growth flushes, percent deer browse, and percent of trees hardened off as of Nov. 1, 1993 for nonexcavated northern red oak growing under factorial combinations of subsoiling, tilling, and fertilization.

Treatment	n	No. Flushes	Deer Browse	Percent of[1] Trees Not Hardened-off
			---(%)---	
Subsoil				
No	318	1.56[2]	22	3
Yes	318	1.72	18	7
Till				
No	318	1.74 a	22	6
Yes	318	1.53 b	17	5
Fertilize				
No	318	1.20 a	13 a	1 a
Yes	318	2.08 b	27 b	9 b

[1]Trees with succulent growth and incompletely developed buds on the newest flush were considered not yet hardened off.
[2]Different letters indicate statistically significant differences at α=0.05 level of significance.

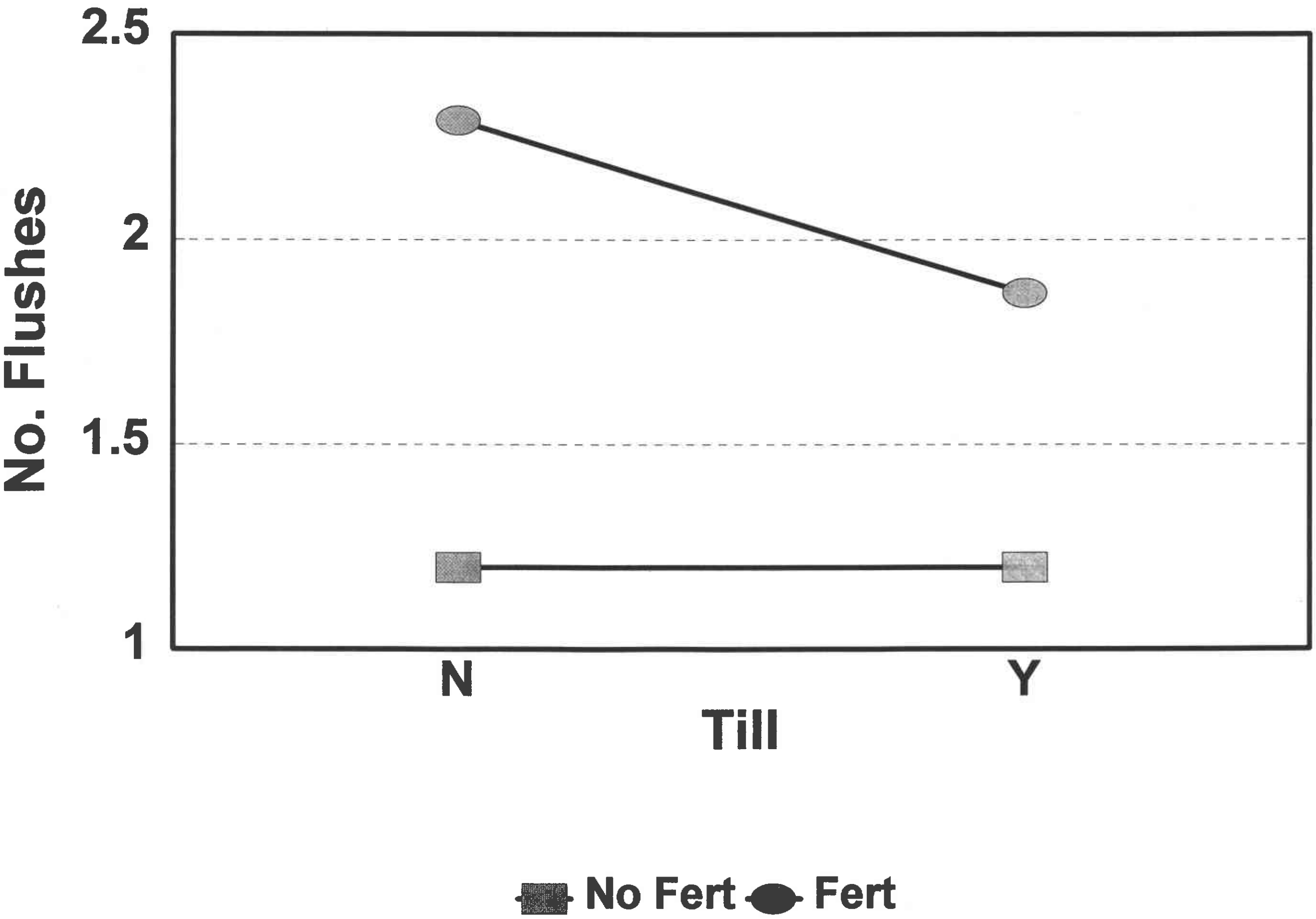


Figure 3. Interaction in the number of growth flushes between tilled treatments and fertilization treatments.

treatments, but it gives some indication of how fertilization may influence dormancy and stem hardening in anticipation of cold temperatures. The first frost at the study site occurred in mid-October while the first snow accumulation occurred in late October, 1993. Many of the fertilized trees still bore green leaves that did not show signs of impending senescence. The winter of 1993/94 was marked by below normal temperatures with periods of as long a one week where temperatures dropped to as low as -18° C. By April 1994, none of the seedlings in any of the treatments were damaged by the harsh winter conditions.

Many studies on hardwood regeneration in the *Central Hardwood Region* are incomplete without assessing the impacts of deer browsing. In fact, the deer seemed to prefer fertilized trees (Table 4). By the end of May of the first growing season, browsing had occurred on 27% of the fertilized trees while only 13% of the non-fertilized trees were browsed. In spite of the heavy browse, fertilized trees were able to respond to the browsing by reflushing and thus still outperformed the non-fertilized trees.

Nutrient relations. It appeared that in the first growing season, fertility was an overriding factor on this site. If any nutrients were possibly limiting tree growth, fertilization should not only produce an increase in growth rate but also increase concentrations of those nutrients in the foliage. Foliage nitrogen (N) concentrations (2.12 %) were significantly higher in fertilized trees than concentrations in non-fertilized trees (1.87 %) (Table 5). Phosphorus (P) and Calcium (Ca) concentrations were also significantly greater in the foliage of fertilized trees (0.11 % and 0.87 %, respectively) than non-fertilized trees (0.103 % and 0.78 %, respectively). Foliage potassium (K) and magnesium (Mg) concentrations did not respond to fertilization. Foliage color reflected these differences in nutrient concentrations. Most fertilized trees had dark green foliage while most non-fertilized trees had a greenish-yellow or even a very chlorotic appearance.

Table 5. Mean foliage nutrient concentrations for northern red oak growing under factorial combinations of subsoiling, tilling, and fertilization.

Treatment	n	N	P	K	Ca	Mg
		(%)				
Subsoil						
No	16	1.97[1]	0.107	0.587	0.867	0.296
Yes	16	2.01	0.106	0.568	0.793	0.299
Till						
No	16	1.95 a	0.107	0.588	0.861	0.306
Yes	16	2.03 b	0.106	0.568	0.798	0.289
Fertilize						
No	16	1.86 a	0.103 a	0.588	0.782 a	0.293
Yes	16	2.12 b	0.110 b	0.568	0.878 b	0.301

[1]Different letters indicate statistically significant differences at α=0.05 level of significance.

Soil fertility appeared to be the main factor limiting tree growth. Therefore, height growth should be correlated with foliage N concentration. In fact, there was a significant relationship between height growth and foliage N concentration ($p < 0.0133$), following a simple linear regression, but the two variables were not strongly correlated (R^2 =0.16)(Figure 4). Neither P nor Ca concentrations were highly correlated with height growth and it is uncertain whether any other of the applied nutrients were necessary to produce this growth response. As increased N availability increases growth rates, demand for all other nutrients increases as well, therefore a balance of nutrients may produce a more long-term, sustained higher level of productivity.

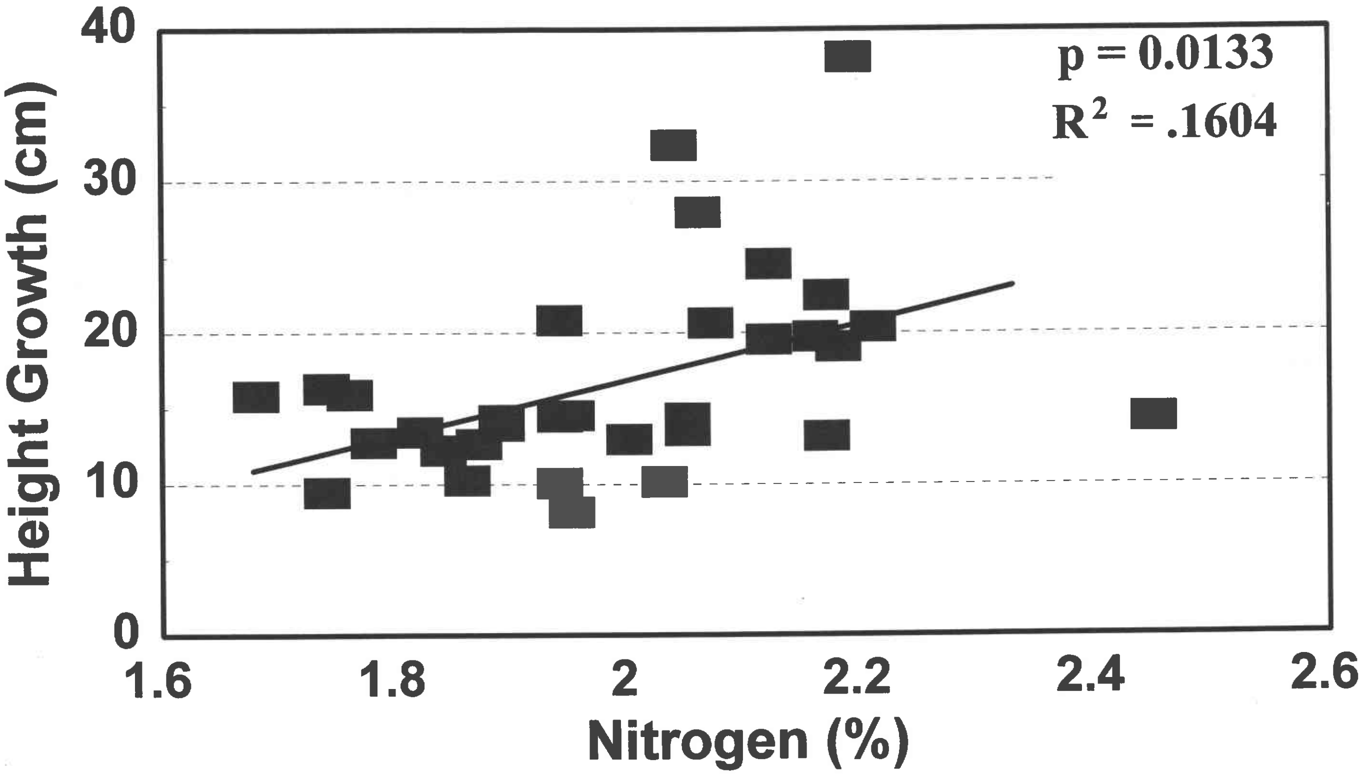


Figure 4. First-year height growth as a function of foliage N concentration for northern red oak growing under factorial combinations of subsoiling, tilling, and fertilization.

Although there was not a strong correlation between height growth and foliar N concentration, the number of flushes as a function of foliage N concentration was highly significant (p>F=0.0001) and strongly correlated (R^2=0.45)(Figure 5). Height growth was also strongly correlated (R^2=0.56) with the number of growth flushes (Figure 6). Therefore, the increased availability of N appeared to increase height growth indirectly by increasing the number of flushes during the growing season. Longman and Coutts (1974), Borchert (1975), and Reich et al. (1980) all reported on the occurrence of episodic shoot growth of northern red oak or other oak species; episodic shoot growth defined as periods of shoot elongation interspersed by periods of rest within the same growing season. Crow (1988) reported that under normal field conditions, oaks produce only one flush of growth and surmised that rapid growth of oak seedlings depends on multiple growth flushes within a single growing season. He also concluded that more information was needed on factors that control recurrent flushing so that conditions could be influenced or manipulated to encourage multiple growth flushes. Nutrient availability, particularly N, appears to be one of those controlling factors, and fertilization may be one way to influence site conditions to promote multiple growth flushes.

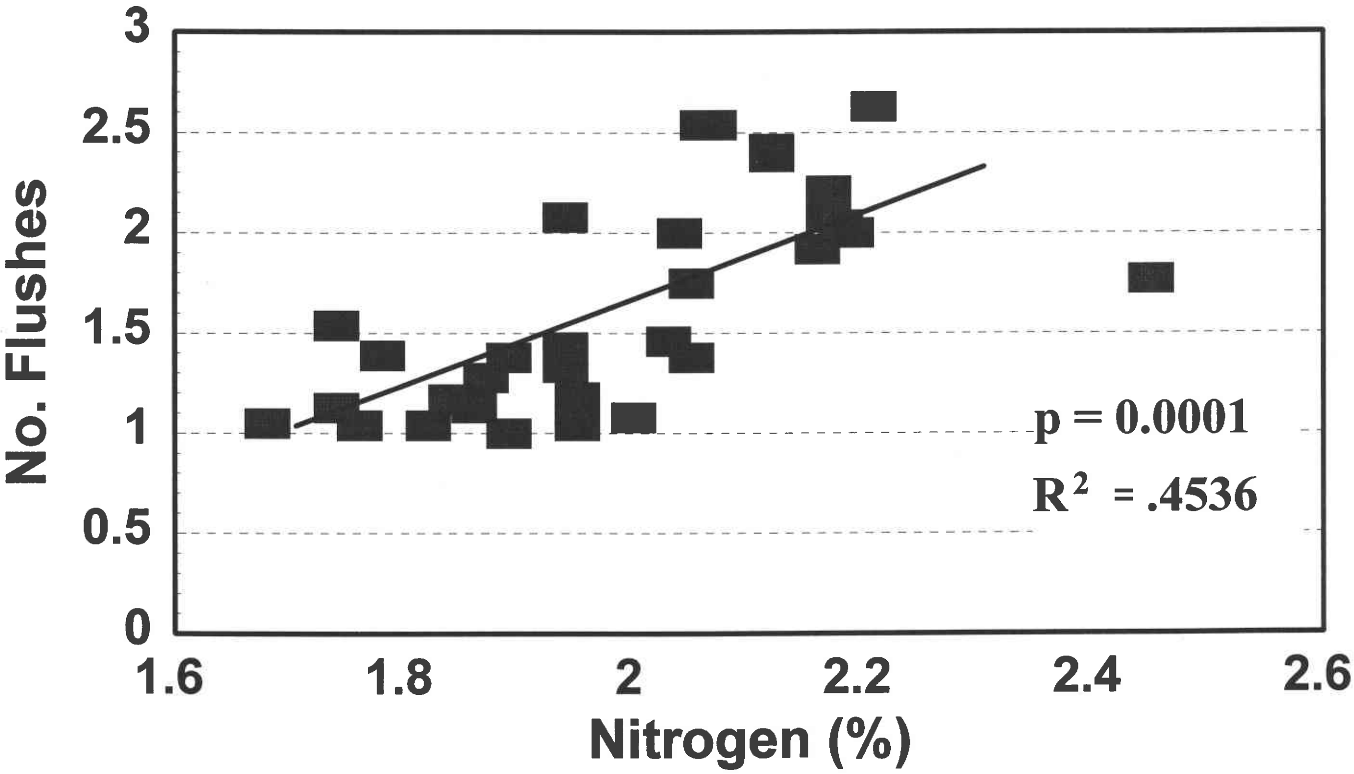


Figure 5. Number of growth flushes in the first year as a function of foliage N concentration for northern red oak growing under factorial combinations of subsoiling, tilling, and fertilization.

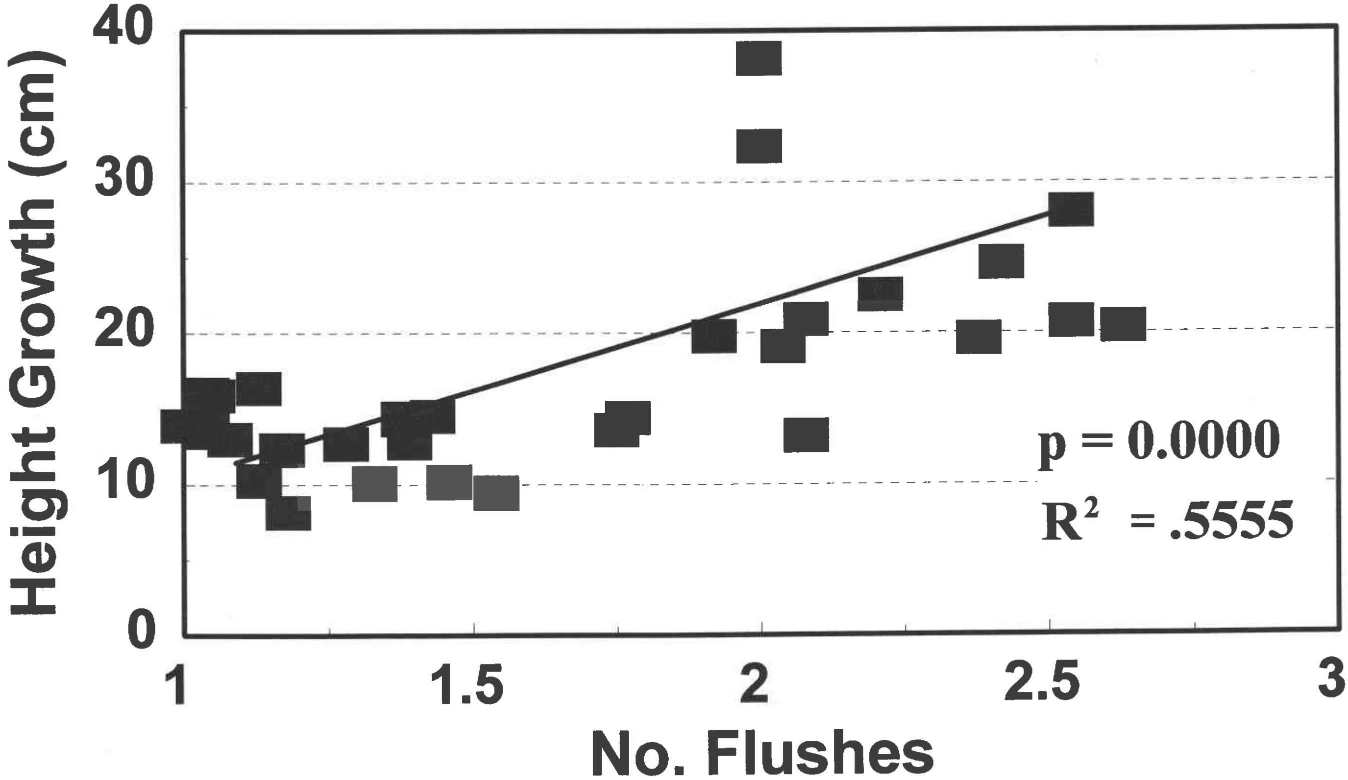


Figure 6. First-year height growth as a function of the number of growth flushes for northern red oak growing under factorial combinations of subsoiling, tilling, and fertilization.

CONCLUSIONS

The use of larger or graded planting stock significantly improves early northern red oak seedling establishment and growth. This study, along with many other studies show the importance of either growing larger stock in the nursery or culling or grading stock prior to planting.

Subsoiling improved rooting depth but no other root or stem parameters in the first growing season. Fracturing the subsoil horizon and allowing deeper root penetration at an early stage may have been more critical in a normal- or below normal- precipitation year. Tilling did not improve root growth and, with the exception of total shoot biomass, did not improve height or diameter growth. Tilling actually reduced the number of flushes in the first growing season presumably because of the more exposed condition it created for the seedlings.

Soil fertility was the most limiting factor on this site and is probably limiting on many other similar old field sites throughout the region. A high rate of N fertilization increased height growth, diameter growth, and total root biomass without altering root:shoot ratios. An increase in height growth was accomplished primarily by increasing the number of growth flushes. Fertilization of hardwood plantations in the Central Hardwood Region is not commonly practiced and rarely even considered as a viable silvicultural tool. Many hardwood plantings are made on recently row-cropped soils where tree seedlings benefit greatly from residual soil fertility. Although the results of this study are preliminary, old field sites or other low-fertility sites may be likely candidates for fertilizer applications to improve early oak establishment and growth. Treatment effects will be monitored through the establishment phase of the plantation.

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